IONIZATION SOURCE UTILIZING A MULTI-CAPILLARY INLET AND METHOD OF OPERATION

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0001] This invention was made with Government support under Contract DE-AC06-76RLO 1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

CROSS REFERENCE TO RELATED APPLICATIONS

[0002] Not Applicable

FIELD OF THE INVENTION

[0003] The present invention relates generally to a method and apparatus for directing or focusing dispersed charged particles into a low pressure apparatus. More specifically, the invention utilizes a multi-capillary inlet to increase the conductance of ions and other charged particles generated at or near atmospheric pressure into a relatively low pressure region, which allows increased efficiency in transmitting those ions and other charged particles.

BACKGROUND OF THE INVENTION

[0004] A great variety of scientific inquiry is confronted with the challenge of identifying the atomic structure or composition of particular substances. To assist in this identification, a variety of schemes have arisen which require the ionization of the particular substances of interest. Many of these analytical techniques, as well as the other industrial uses of charged particles, are carried out under conditions of high vacuum. However, many ion sources operate at or near atmospheric pressures. Thus, those skilled in the art are continually confronted with challenges associated with transporting ions and other charged particles generated at atmospheric or near atmospheric pressures into regions maintained under high vacuum.

[0005] An illustrative example of this general problem is presented in the use of electrospray ionization when combined with mass spectrometry as an analytical technique. Electrospray ion sources (which broadly includes, but is not limited to, nano electrosprays, conventional electrosprays, micro-electrospray, and nebulizing gas assisted electrospray) are widely used with mass spectrometry for sample analysis, for example in biological research. For m/z analysis, ions are typically created at atmospheric pressure by the electrospray ion source and are then transported to the high vacuum region of a mass spectrometer through a capillary inlet that penetrates the first chamber of the mass spectrometer. A differential pumping system involving several stages for stepwise pressure reduction is commonly used to achieve the vacuum conditions conventionally utilized in m/z analysis within the mass spectrometer, and the major design issues are generally related to optimizing overall ion transmission efficiencies.

[0006] Improved transmission efficiencies in the intermediate vacuum stages have been achieved by using the recently developed RF ion funnel at higher interface pressures (~1 to 10 Torr) and RF multi-pole ion guides with buffer gas cooling at lower interface pressures as more fully described in Shaffer, S. A.; Tang, K.; Anderson, G. A.; Prior, D. C.; Udseth, H. R.; Smith, R. D., *Rapid Commun. Mass Spectrom.* 1997, 11, 1813-1817; Shaffer, S. A.; Prior, D. C.; Anderson, G. A.; Udseth, H. R. and Smith, R. D. *Anal. Chem.* 1998, 70, 4111-4119; and Douglas, D. J.; French, J. B., *J. Am. Soc. Mass Spectrom.* 1992, 3, 398-408, and U.S. Pat. No. 6,107,628 entitled Method and Apparatus for Directing Ions and other Charged Particles Generated at Near Atmospheric Pressures into a Region under Vacuum, the entire contents of each of which are herein incorporated into this specification by this reference.

[0007] However, in the region where the ions of interest are generated, the total charge transmission is directly proportional to the cross section area of the inlet orifice diameter or capillary inner diameter. To improve the ion transmission in this region, a larger inlet is clearly desired, but the inlet size is limited by several factors. For example, simply using a larger inside diameter (I.D.) capillary inlet is problematic. First, the desolvation is less effective for larger I.D. capillary inlets because of the greater temperature variation across the capillary radius (resulting in a large variation in droplet desolvation efficiency). A second problem is the ion transmission efficiency in the first vacuum stage may be decreased due to greater gas dynamic effects. Thus, there is still a general need for improved methods for generating ions at atmospheric pressures, and a particular need for an efficient ion transmission while maintaining the effective droplet desolvation for the ion currents relevant to electrospray ionization (ESI) where aerodynamic effects dominate. Ion transmission between an ion source and the first vacuum stage is primarily dependent upon the proximity and gas conductance of the interface inlet.

SUMMARY OF THE INVENTION

[0008] Accordingly, it is an object of the invention in one of its aspects to provide a method for providing an ion or charged particle source in a pressure region at near atmospheric pressures. As used herein, "near atmospheric" pressures are defined as between 10-1 millibar and 1 bar. Also as used herein, the charged particles are defined as being smaller than one billion AMUs. The focusing of the present invention is accomplished by providing an apparatus, hereinafter referred to as a "multi-capillary inlet", which is operated at the interface between an ESI source and the interior of an instrument maintained at near atmospheric pressures. To demonstrate a preferred embodiment of the present invention, a prototype multi-capillary inlet was constructed from an array of seven thin wall stainless steel tubes soldered into a central hole of a cylindrical heating block. However, those skilled in the art will recognize that the advantages of the present invention may be achieved by providing a plurality of narrow passageways or orifices through which a flow of charged particles may be directed, regardless of the particular method of fabrication. While interfaces formed of capillaries as described herein are the preferred method of fabrication, interfaces having essentially equivalent physical dimensions can be fabricated by a variety of means well known to those having skill in the art, and the use of the term "multi-capillary" should not, therefore, be construed to limit the scope of the invention. Rather, the present invention should be construed as including any apparatus whereby a plurality of passageways are formed as the interface between an ion source, such as an ESI, and the interior of an instrument maintained at near atmospheric